A national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy

Western Wind and Solar Integration Study

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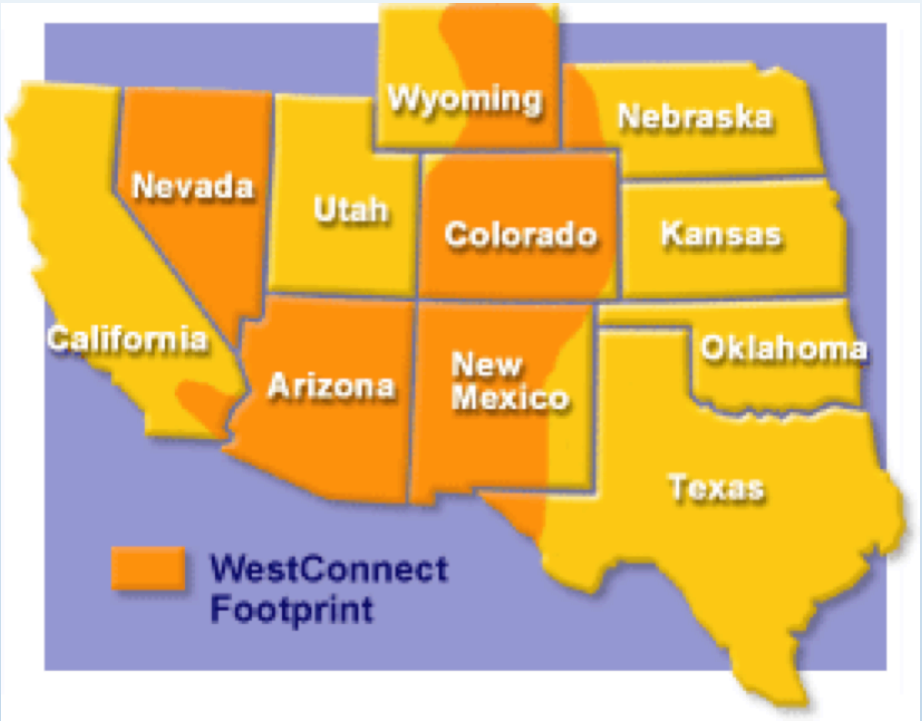
SWAT/CCPG
Aug 19, 2009

Overview

- Goal
  - To understand the costs and operating impacts due to the variability and uncertainty of wind, PV and concentrating solar power (CSP) on the WestConnect grid
- Utilities
  - Arizona Public Service
  - El Paso Electric
  - NV Energy
  - Public Service of New Mexico
  - Salt River Project
  - Tri-State G&T
  - Tucson Electric Power
  - Xcel Energy
  - WAPA



SCENARIOS

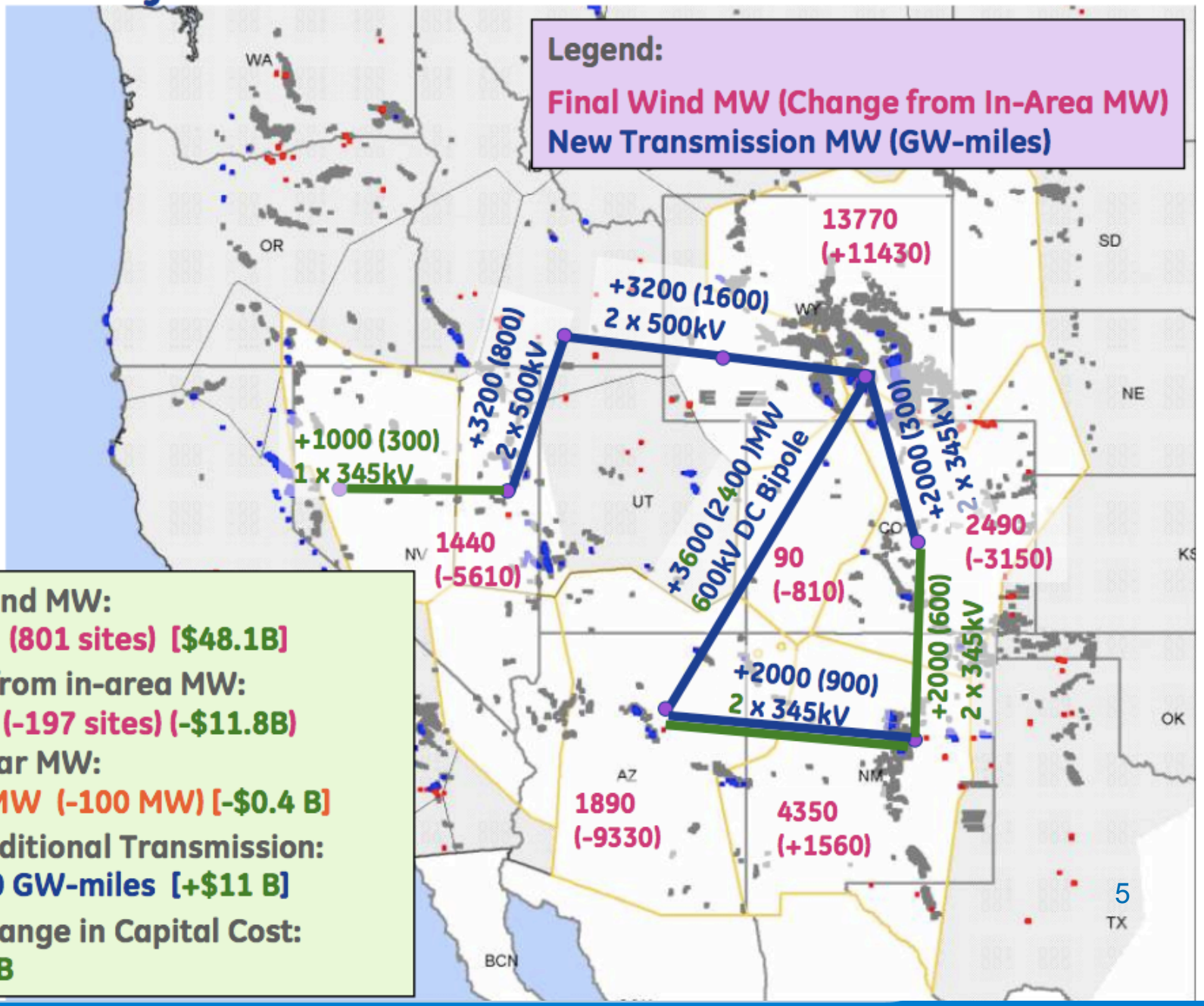
Scenario Overview

In Footprint		Rest of WECC	
Wind	Solar	Wind	Solar
10%	1%	10%	1%
20%	3%	10%	1%
30%	5%	20%	3%

- Baseline – no new renewables
- In-Area – each transmission area meets its target from sources within that area
- Mega Project – concentrated projects in best resource areas
- Local Priority – Balance of best resource and in-area sites
- Plus other scenarios yet to be determined (high solar, high capacity value, high geographic diversity)

Solar is 70% CSP and 30% distributed PV. CSP has 6 hours of thermal storage. Penetrations are by energy.

Mega Project Scenario



Total Wind MW:
24040 (801 sites) [$48.1B]

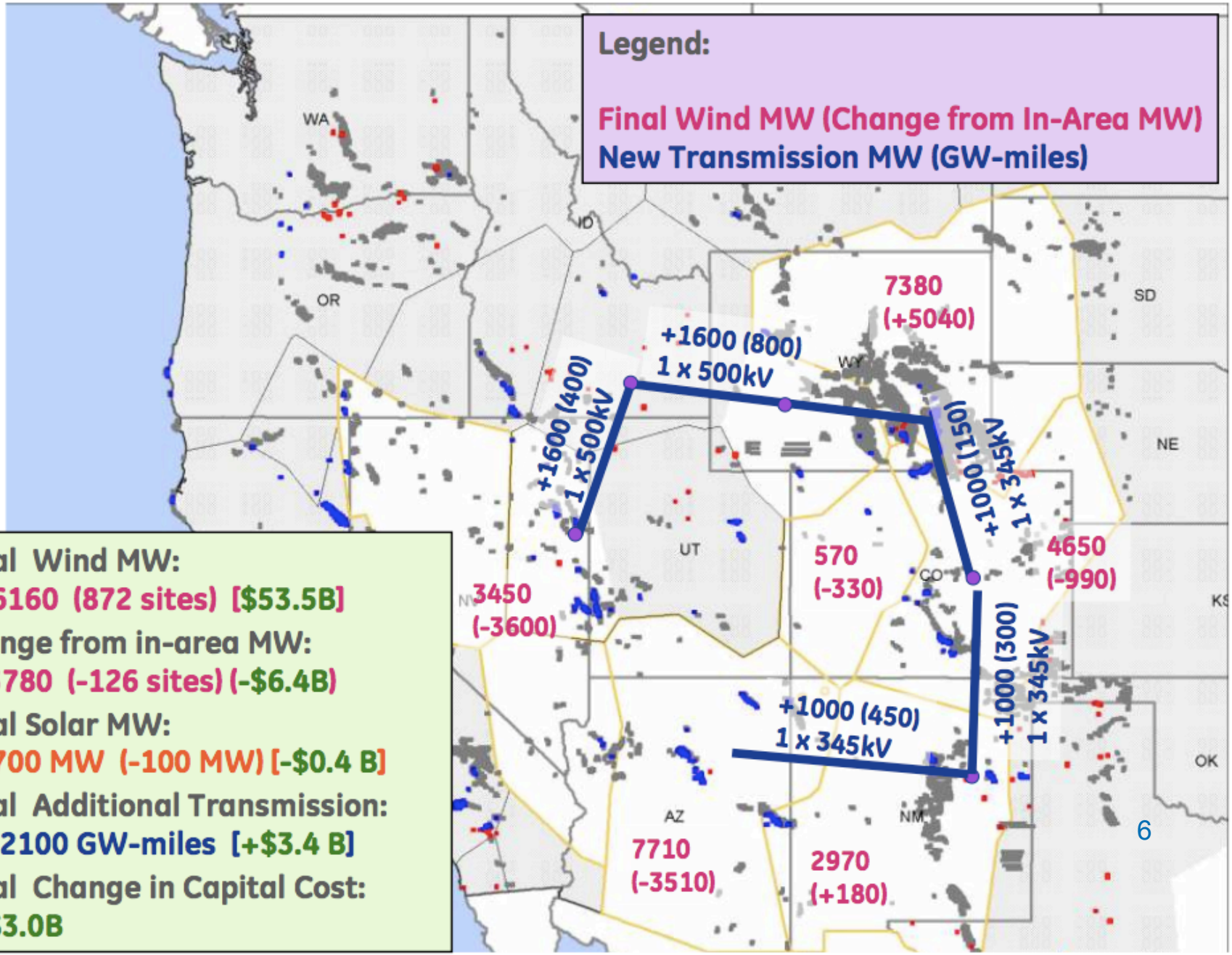
Change from in-area MW:
-5940 (-197 sites) (-$11.8B)

Total Solar MW:
5700 MW (-100 MW) [-$0.4 B]

Total Additional Transmission:
+ 6900 GW-miles [+$11 B]

Total Change in Capital Cost:
- $1.2B

Local Priority Scenario

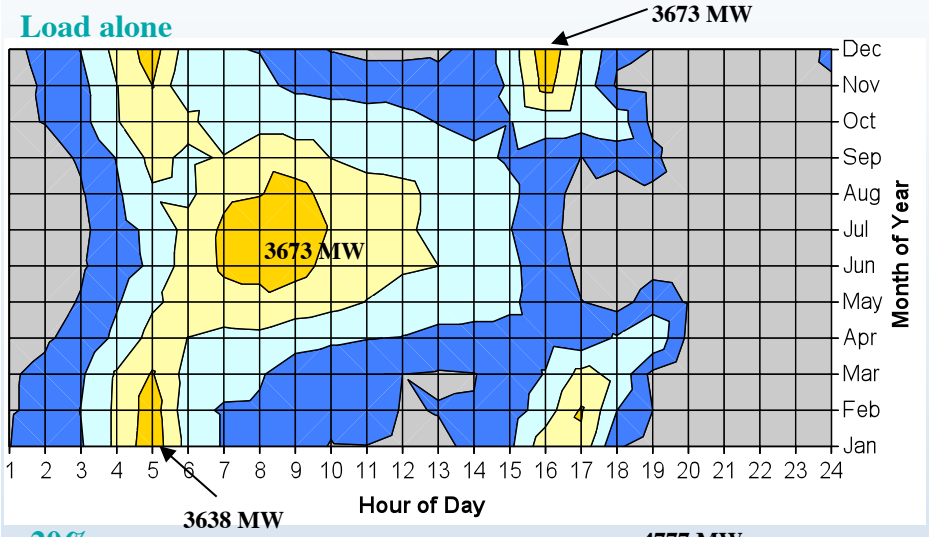


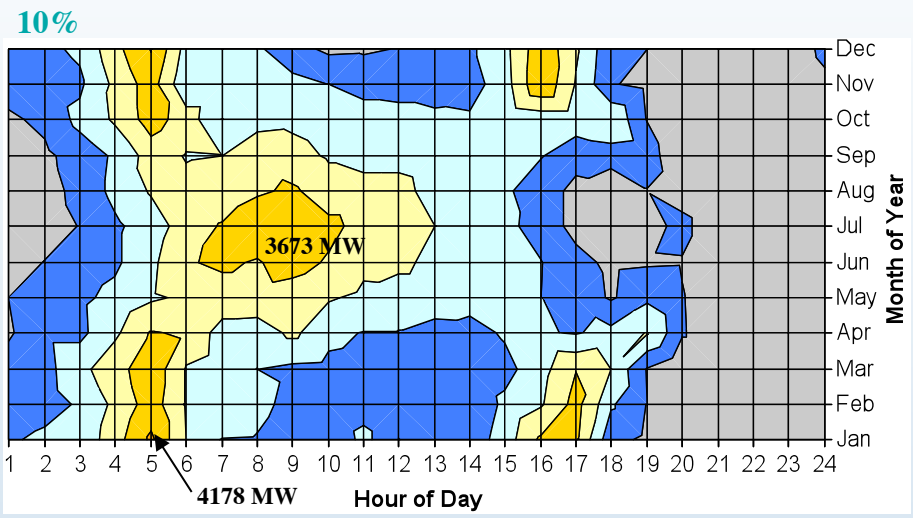
Total Wind MW:
26160 (872 sites) [$53.5B]
Change from in-area MW:
-3780 (-126 sites) (-$6.4B)
Total Solar MW:
5700 MW (-100 MW) [-$0.4 B]
Total Additional Transmission:
+ 2100 GW-miles [+$3.4 B]
Total Change in Capital Cost:
-$3.0B

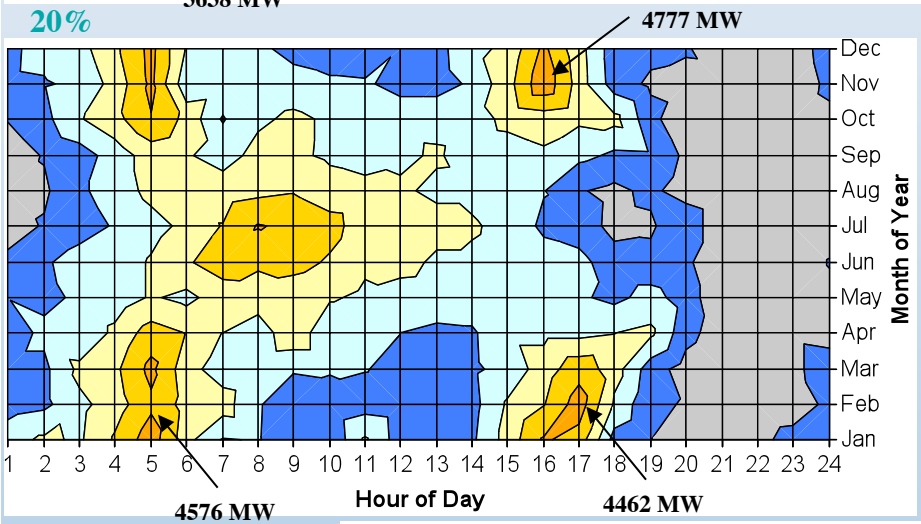
STATISTICAL ANALYSIS

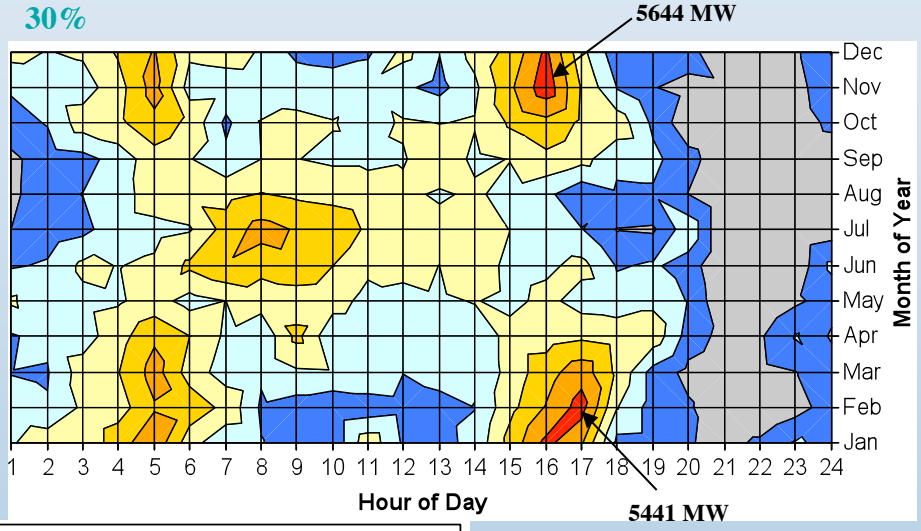
Study Footprint - Timing of Extreme Net Load Up-Ramps

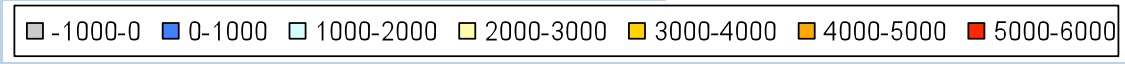
(Local Priority Scenario)









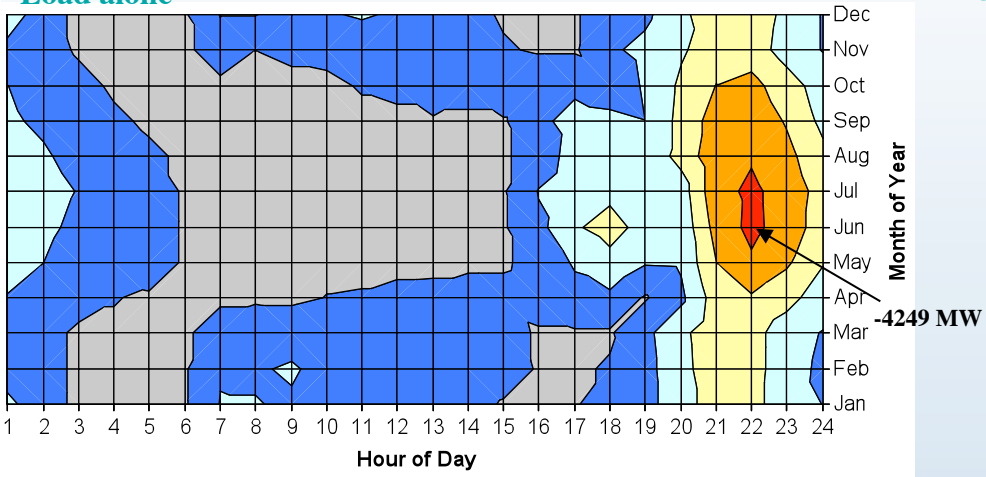


Wind/solar drops drive extreme up-ramps in late afternoons during late fall and winter

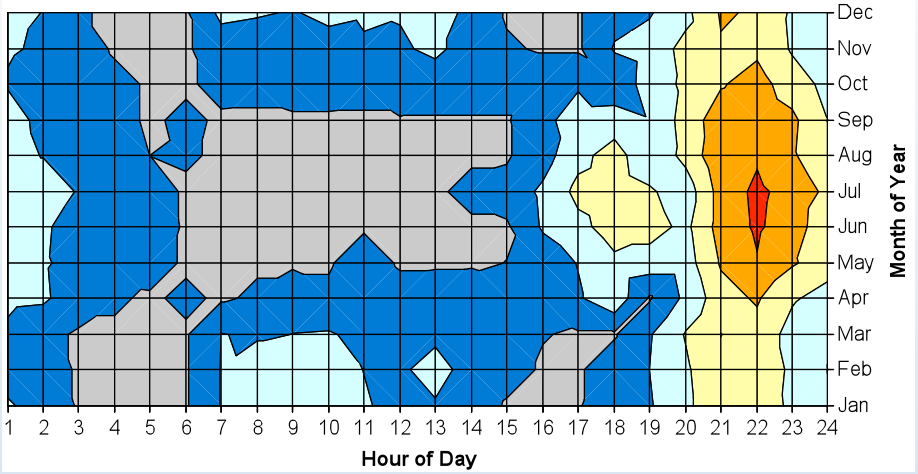
Study Footprint - Timing of Extreme Net Load Down-Ramps

(Local Priority Scenario)

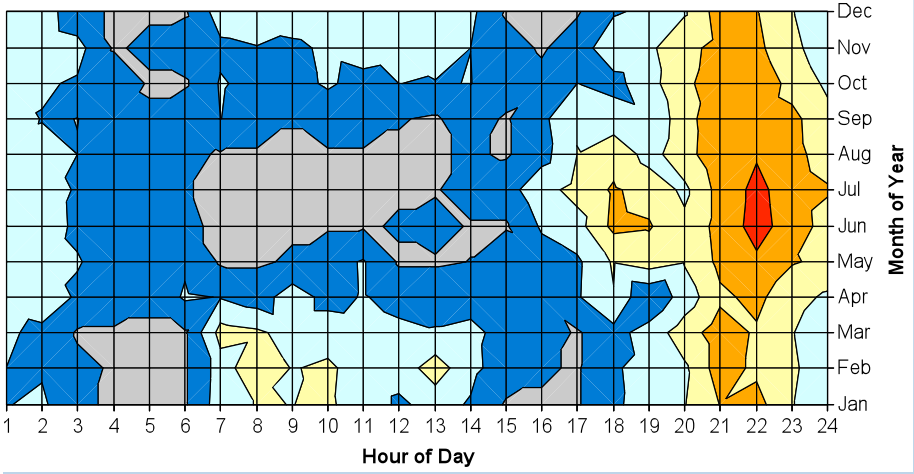
Load alone



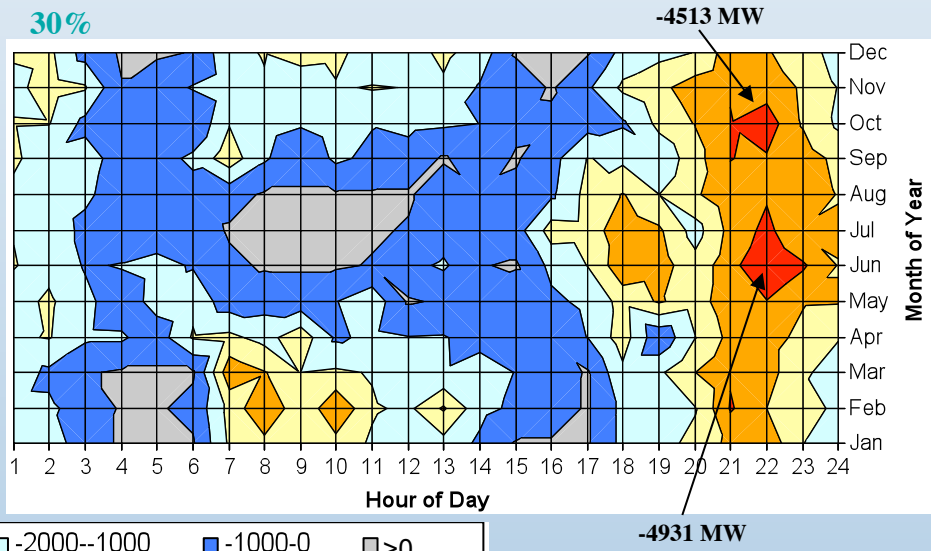
10%

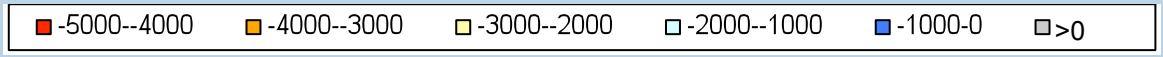


20%



30%

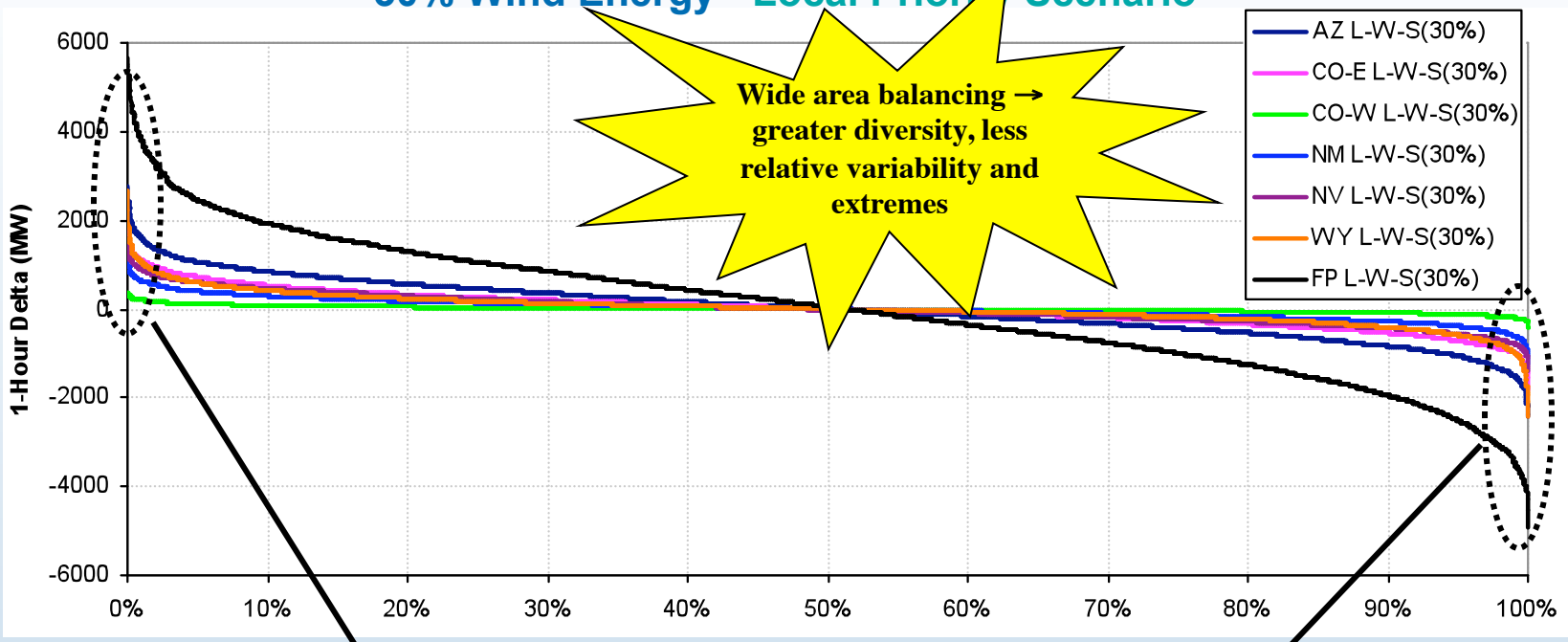


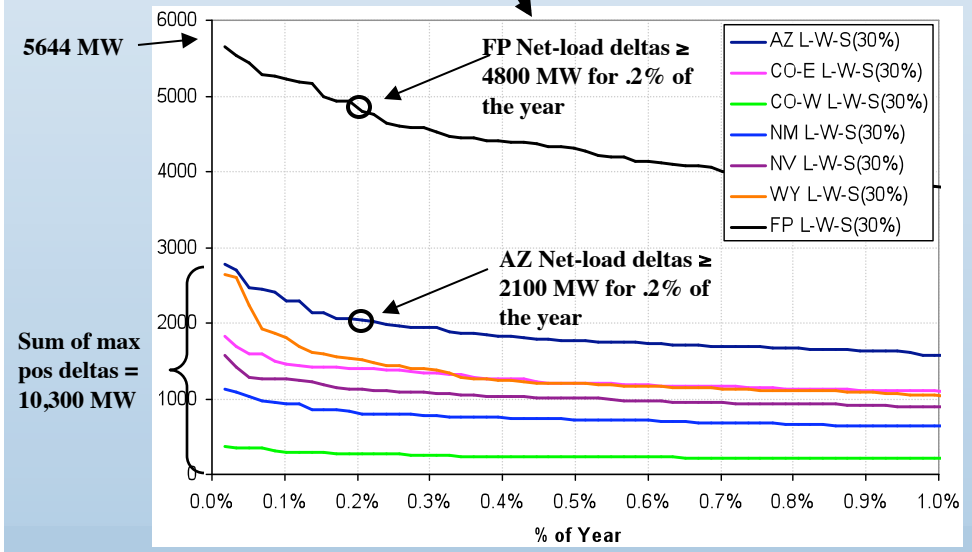


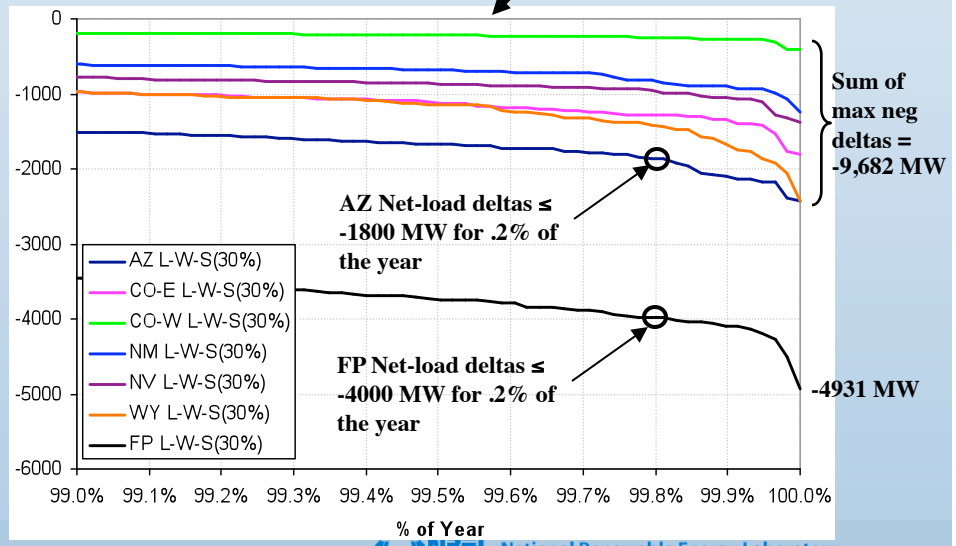
Extreme down-ramps driven by summer/early fall evening load roll-off

Duration of Extreme Hourly Net Load Deltas 2006

30% Wind Energy - Local Priority Scenario





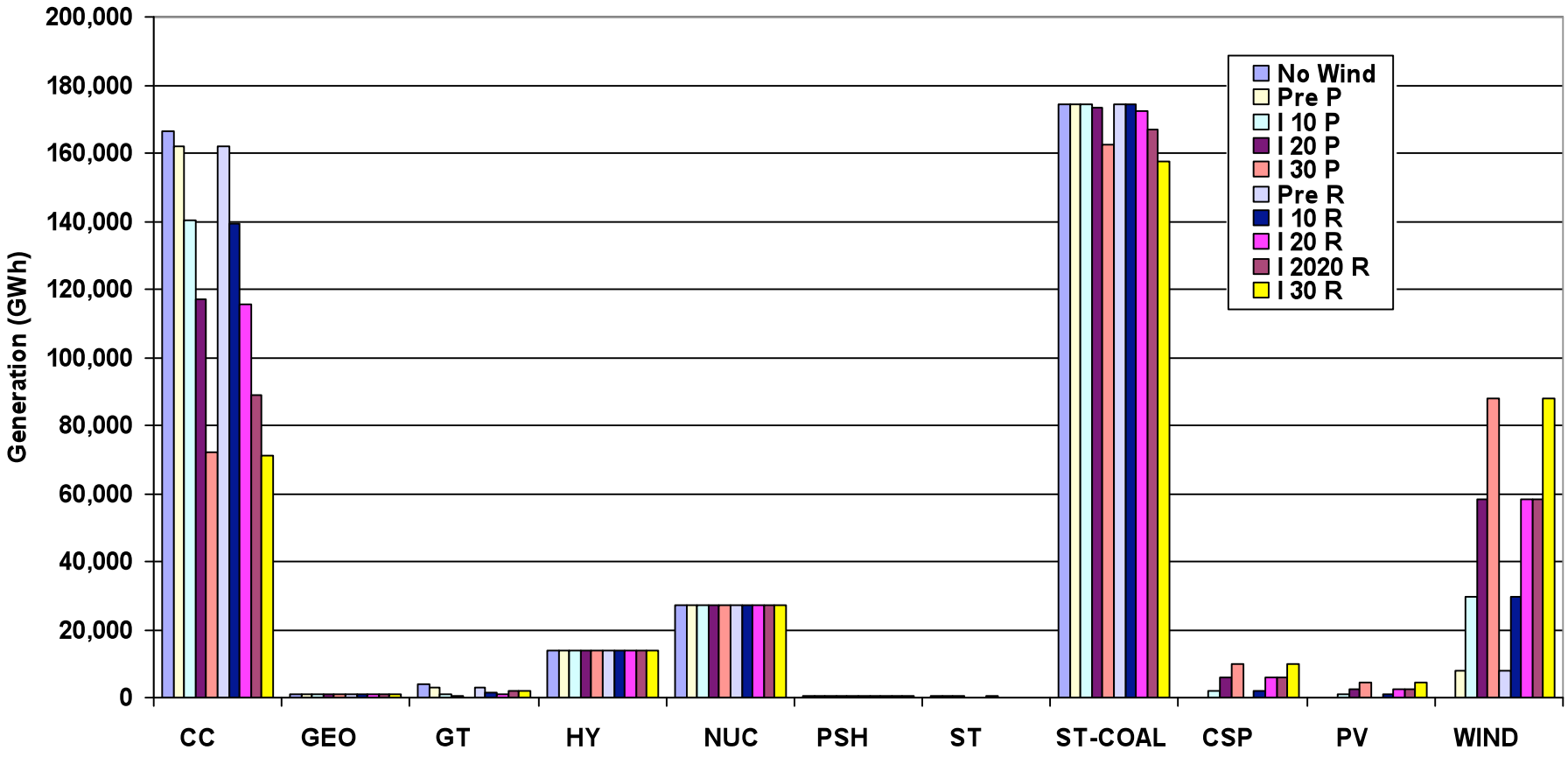


Statistical Analysis Conclusions

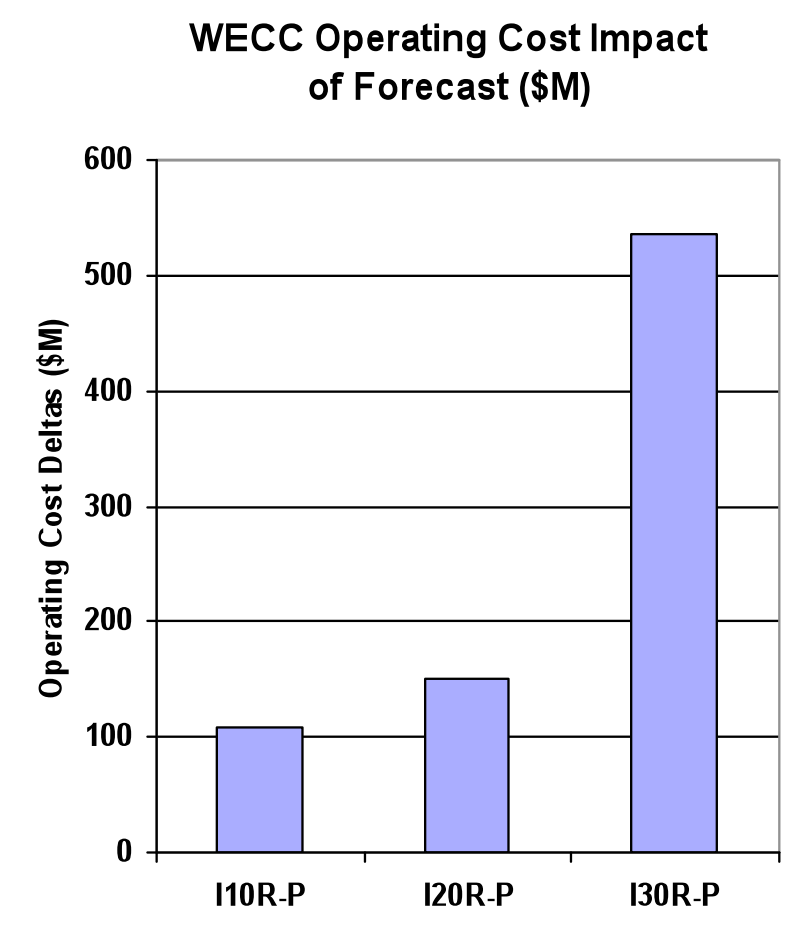
- Significant monthly/seasonal variation of wind and solar energy within footprint and across areas
- Relatively small observable difference among scenarios, but more pronounced at area level
- Load coincidence with wind and solar a large driver of diurnal variability
- At footprint and area level, net load variability tends to be high during fall/winter late afternoons due to simultaneous load rise, and wind/solar roll-off
- Extreme net load down-ramps in summer/early fall driven by evening load roll-off
- There is a good case to be made for load participation in reducing ramping requirements
- Wide area balancing → greater diversity, less relative variability and extreme ramps
- Forecast error is not a linear function of the wind forecast → discounting forecast to increase spin may not to be a good option

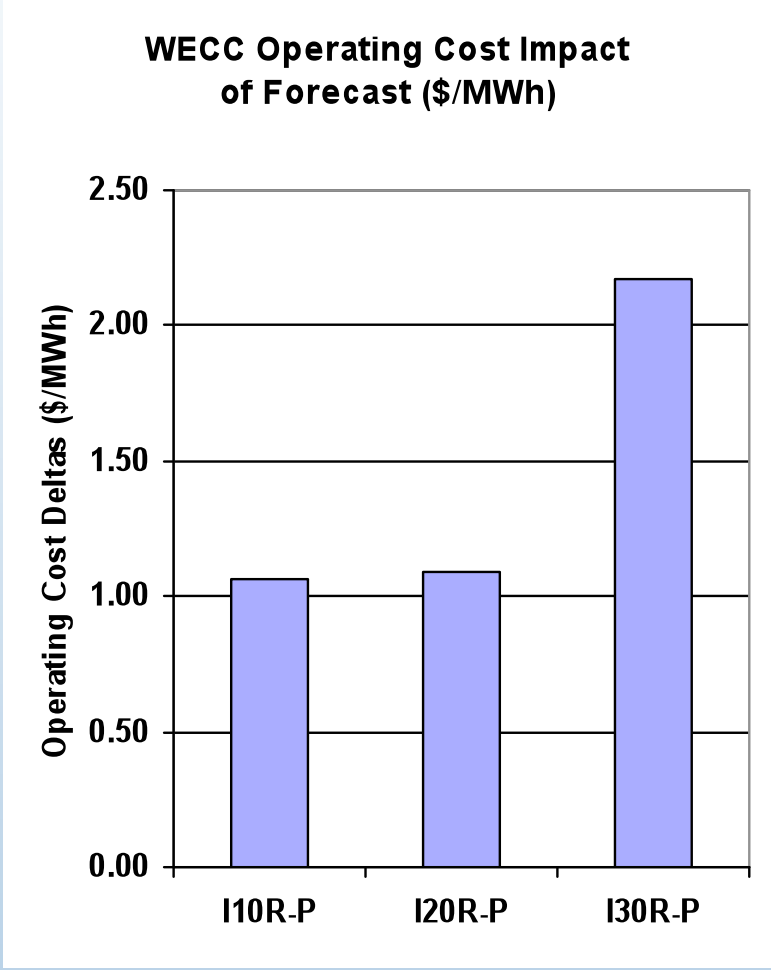
PRODUCTION SIMULATION ANALYSIS

Generation by Type - Study Area - 2006

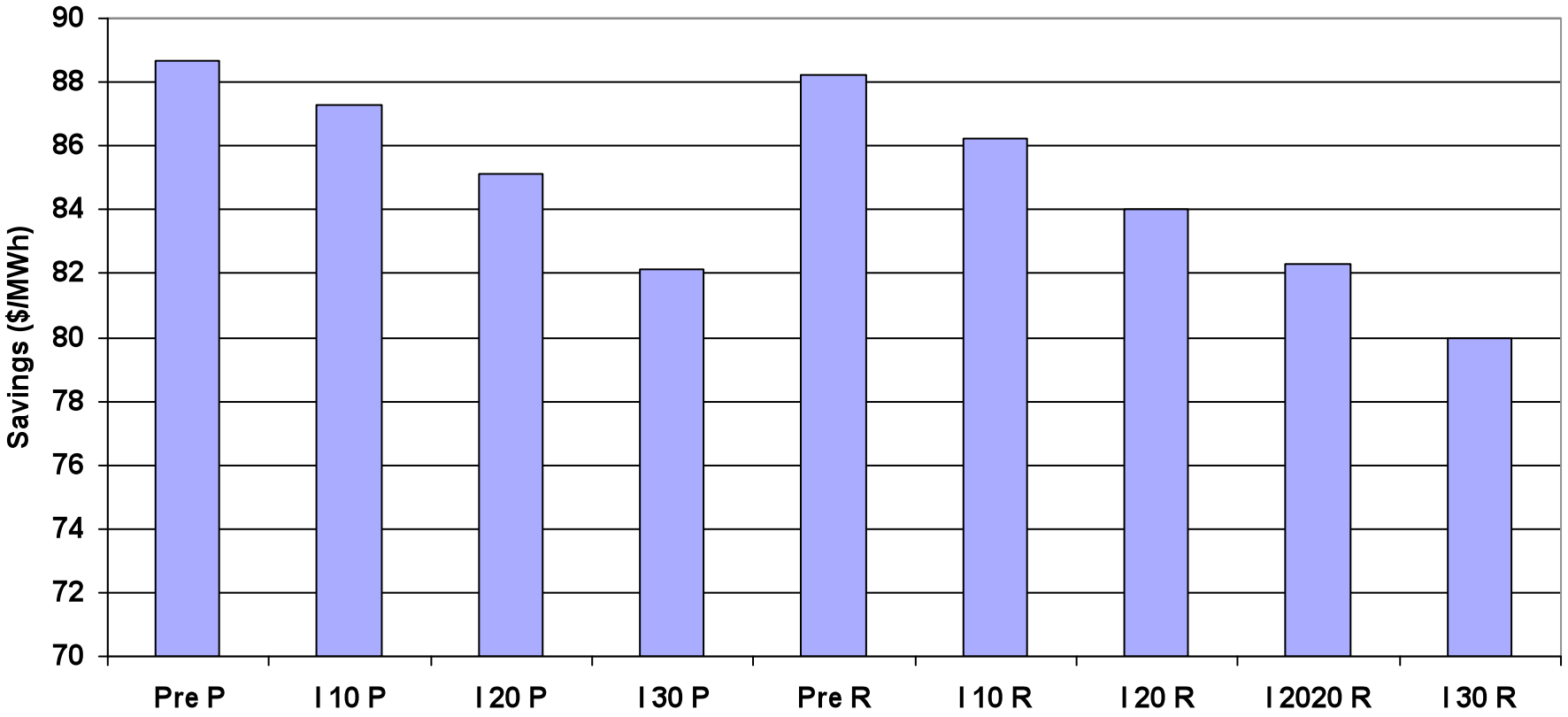


Value of Renewable Forecast

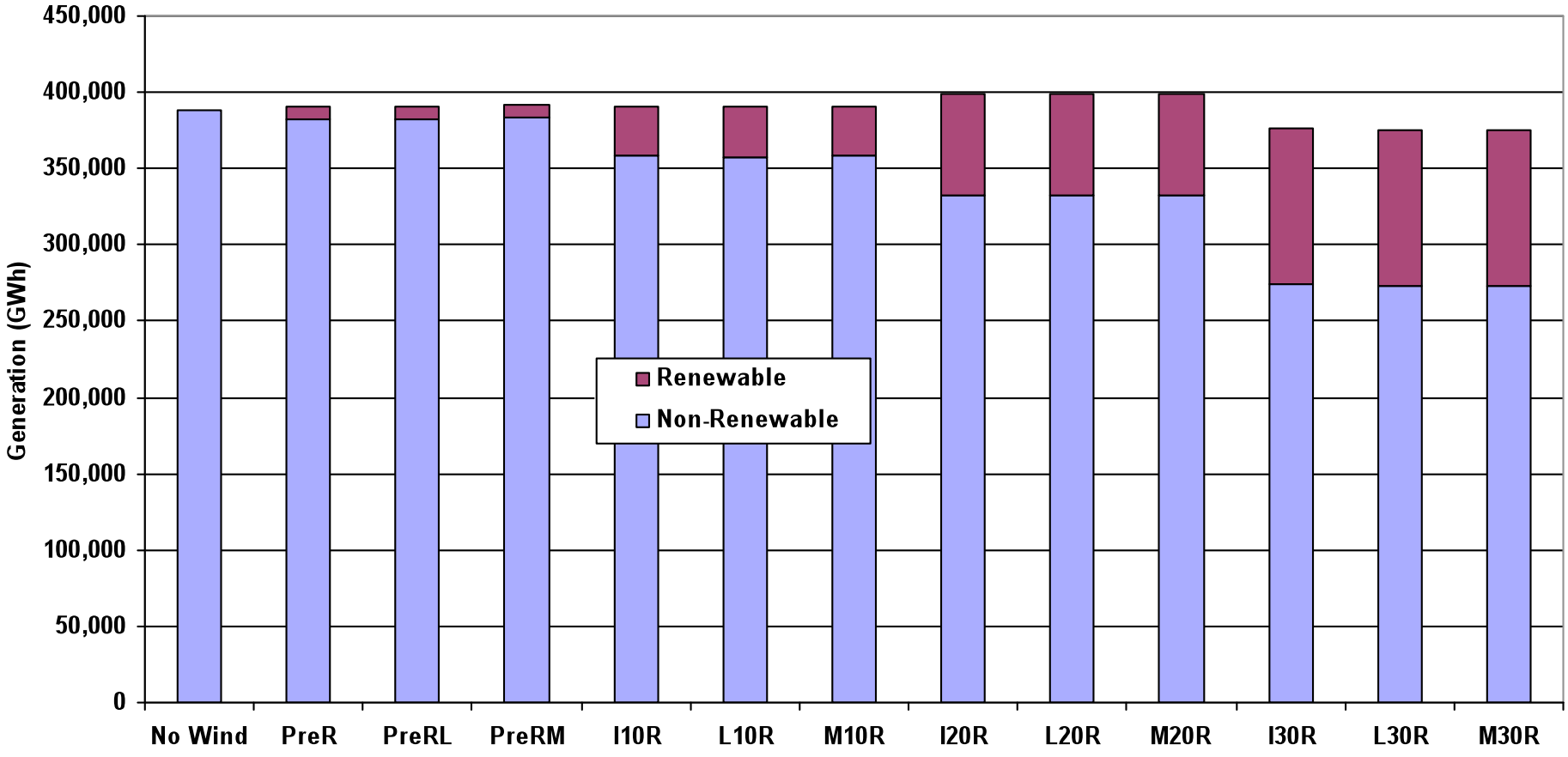




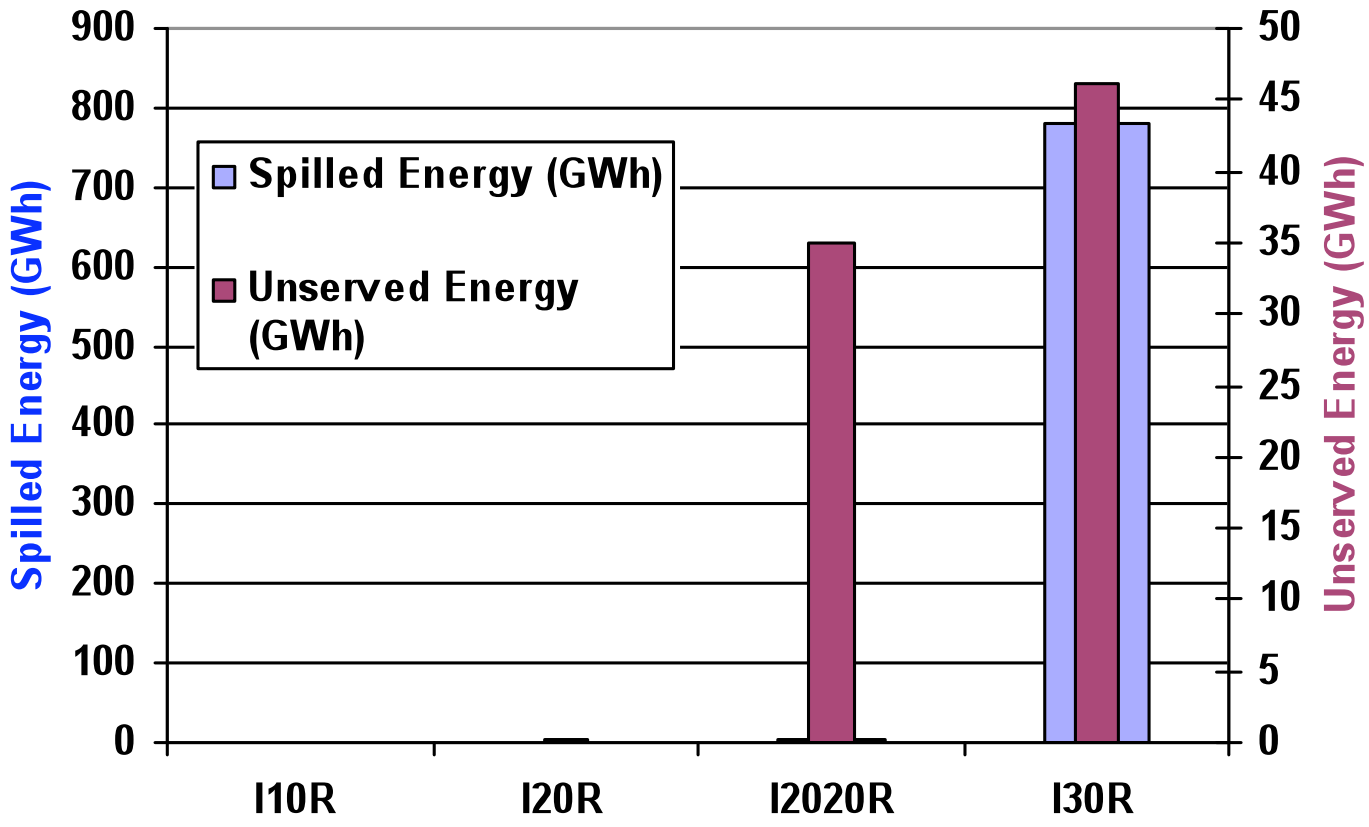
Operating Cost Savings per MWh of Renewable Energy ($/MWh) - WECC - 2006



Total Generation - Study Area - 2006



Impact of Renewables in Neighboring Areas

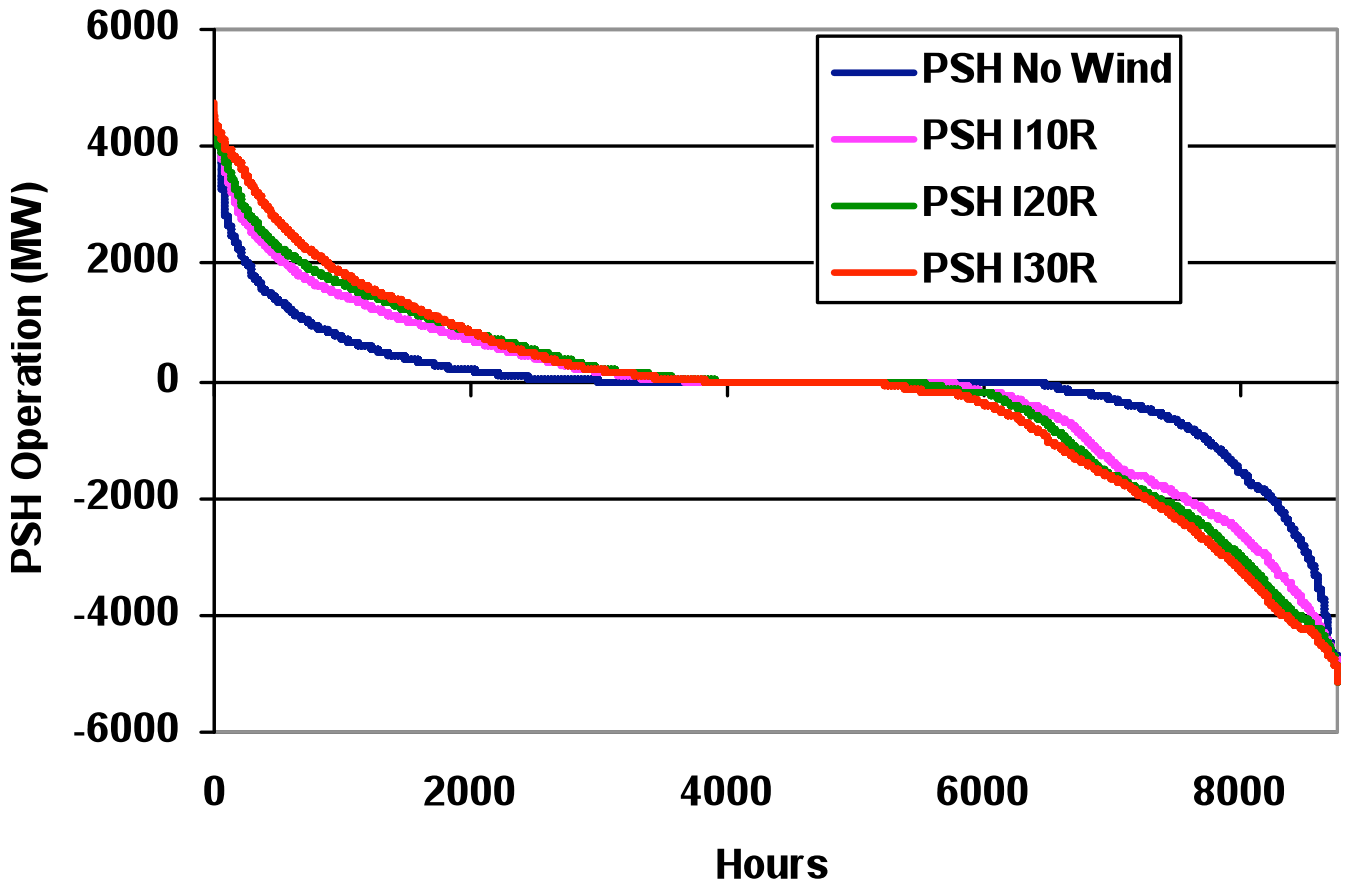


Operational Observations

- Forecasts are critical
  - Significant variations in impact for the same wind variability with different forecasts
- No significant issues at penetrations up to 20% in study footprint and 10% outside
- Impact more severe at 30% inside and 20% outside
- Operational impact dependent on what your neighbor is doing
- At higher penetrations it is essential that “demand” is an active participant.

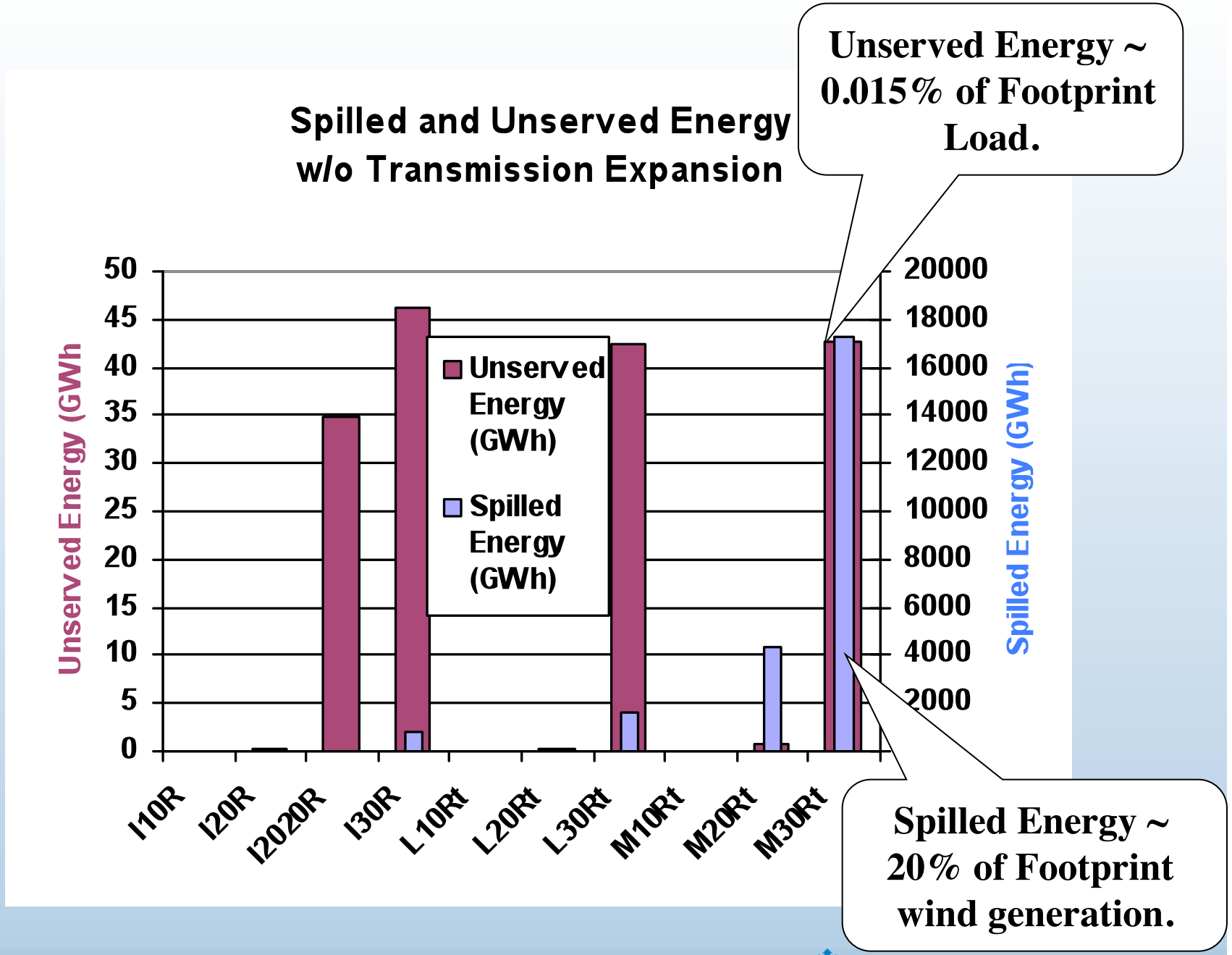
Impact of Scenarios

- Energy generation was held constant for the various scenarios but total installed capacity and location was varied.
- No significant variation in operational results between various scenarios.

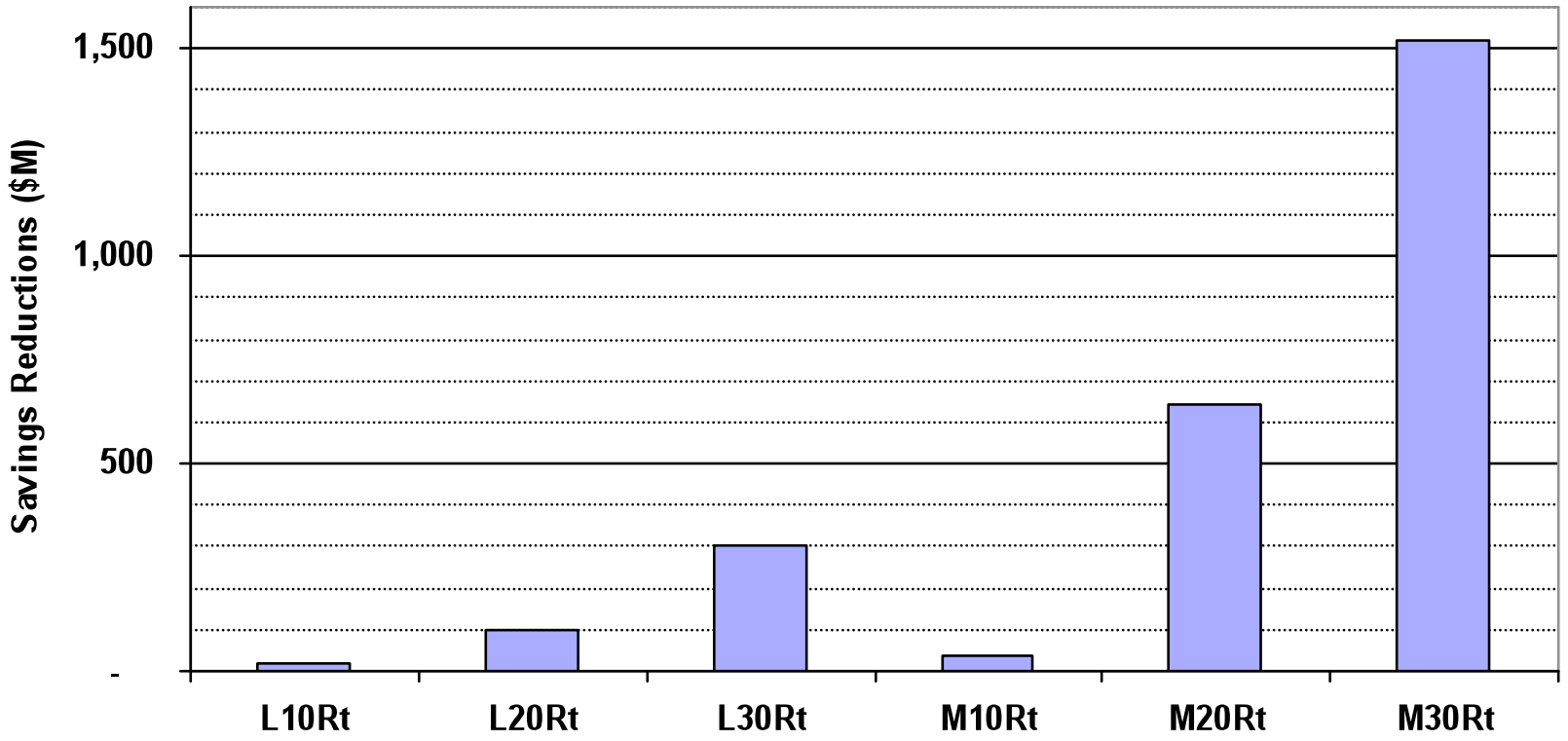

PSH Annual Duration Curve
PSH Operation (MW)
6000
4000
2000
0
-2000
-4000
-6000
0
2000
4000
6000
8000
Hours
PSH No Wind
PSH I10R
PSH I20R
PSH I30R

Transmission Sensitivity

- Examined the Local Priority and Mega Project scenarios without adding any new transmission.


Spilled and Unserved Energy
w/o Transmission Expansion
Unserved Energy ~ 0.015% of Footprint Load.
Unserved Energy (GWh
Spilled Energy (GWh)
Unserved Energy (GWh)
Spilled Energy (GWh)
50
45
40
35
30
25
20
15
10
5
0
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
I10R
I20R
I2020R
I30R
L10Rt
L20Rt
L30Rt
M10Rt
M20Rt
M30Rt
Spilled Energy ~ 20% of Footprint wind generation.

Savings Reductions due to No Transmission Expansion



Reliability Analysis

- Examined In-Footprint region without transmission constraints to determine the capacity value of renewable resources compared to the generation resources and load profiles.
- Examined In-Area Scenario for 2006 load and renewable profiles.
- Considered LOLE in days/yr and hours/yr as well as Unserved Energy in MWh/yr.
- Examined Wind, CSP and PV independently and jointly for varying penetrations.

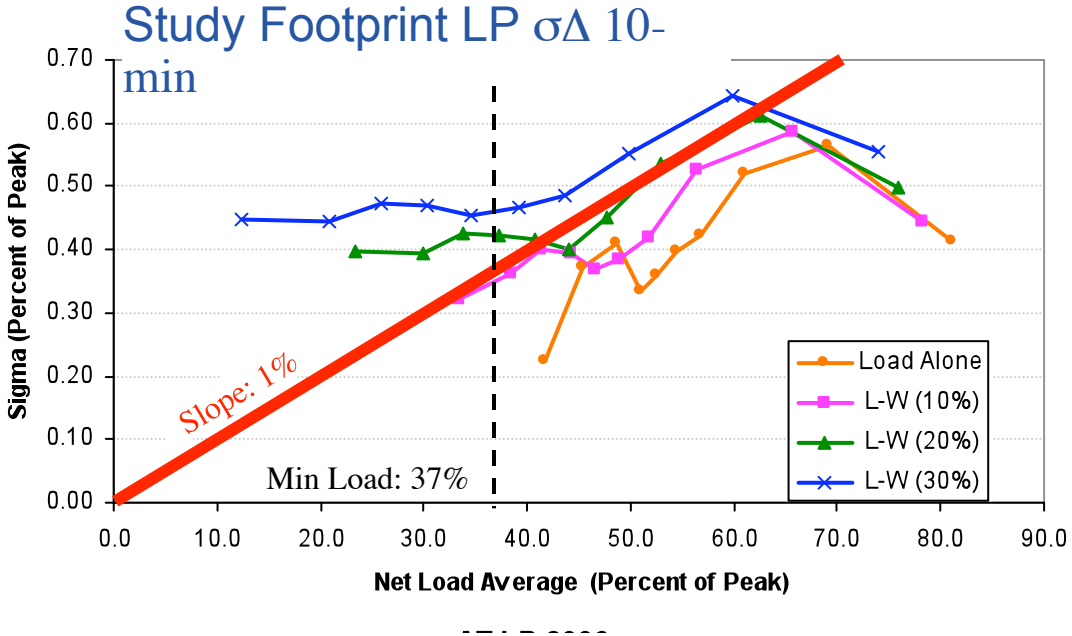
Capacity Values

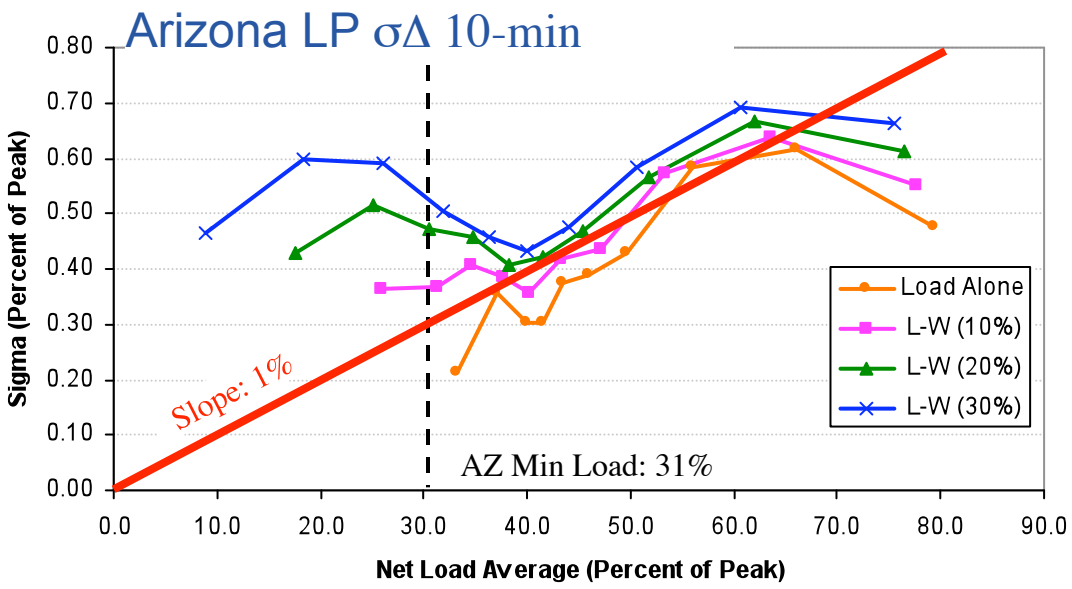
Penetration	Total Renewables MW	Wind MW	CSP MW	PV MW
0%	0	0	0	0
10% Wind, 1% Solar	11,490	10,290	600	600
20% Wind, 3% Solar	23,350	19,950	1,700	1,700
30% Wind, 5% Solar	35,740	29,940	2,900	2,900

Wind + CSP+PV	Wind only	CSP only	PV only
0			
15.8%	11.4%	92.6%	28.6%
17.7%	10.8%	93.3%	26.9%
18.5%	10.7%	92.2%	26.9%

INTRA-HOUR VARIABILITY/ RESERVE REQUIREMENTS

What do we do with σΔ 10-min?
What is relationship to 3% of load for spinning reserve?



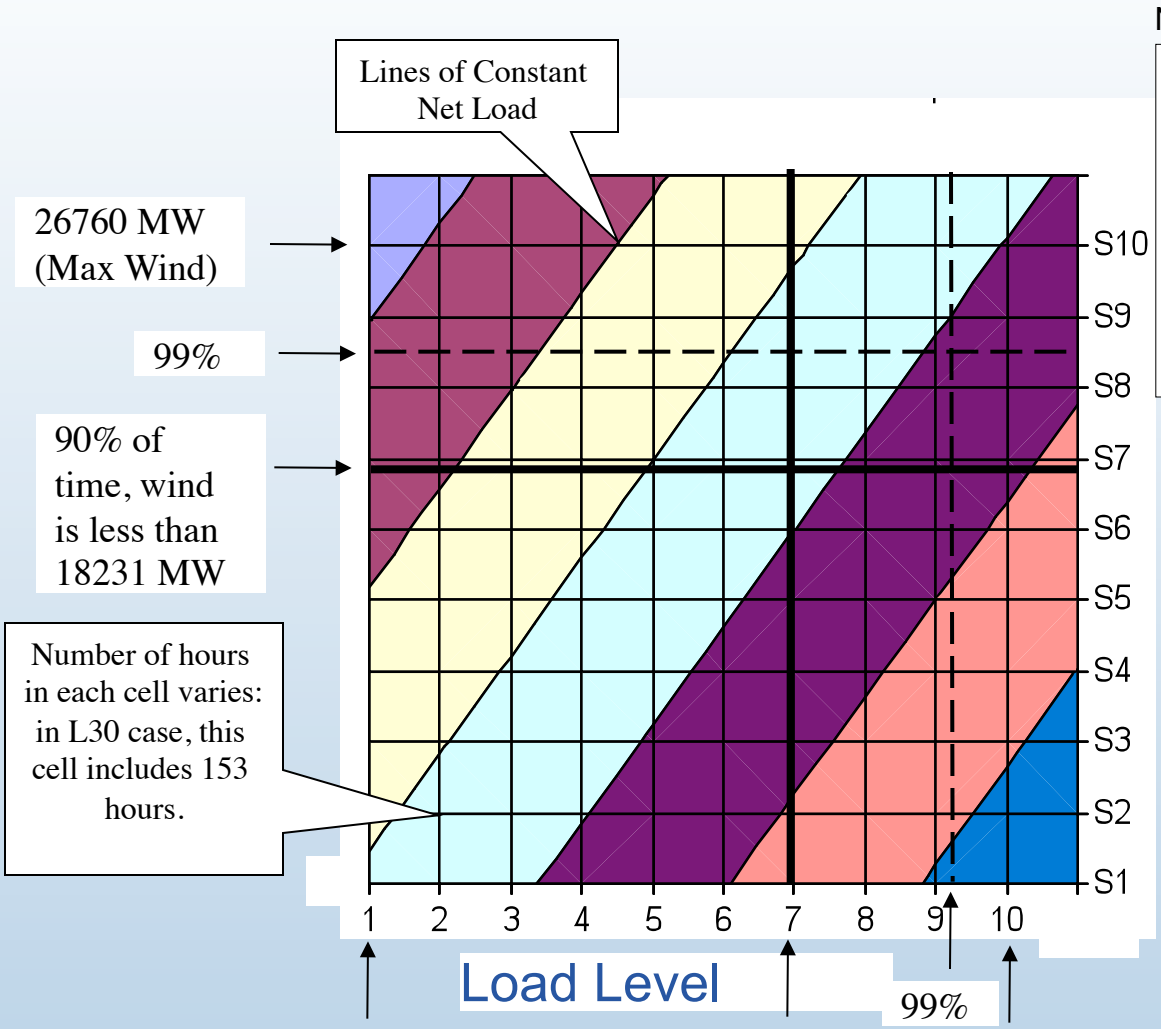


Relationship between 10-min load delta and present spin practice (3% rule):

- Load variability roughly proportional to Load level (up to moderately high loads
- On a large area basis (e.g. AZ), proportionality is ~ 1% of load
- Therefore, 3% of load rule roughly corresponds to 3σ of 10-min variability
- We will build on this relationship, that is:

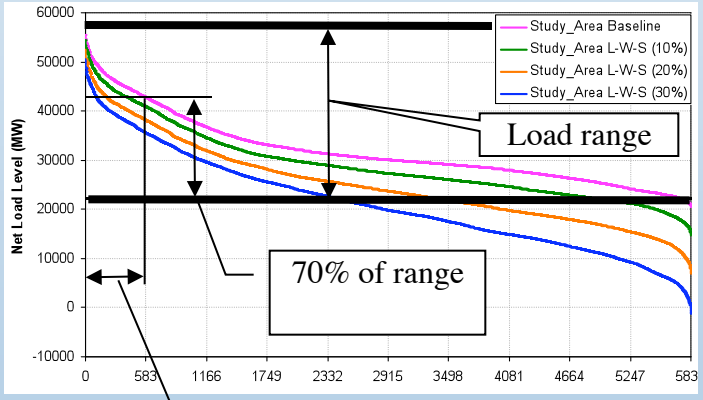
For all operating conditions there is an implied reserve requirement: 3 x σ 10-min Δ Net Load

L30 Load - Wind - Net Load Relationship



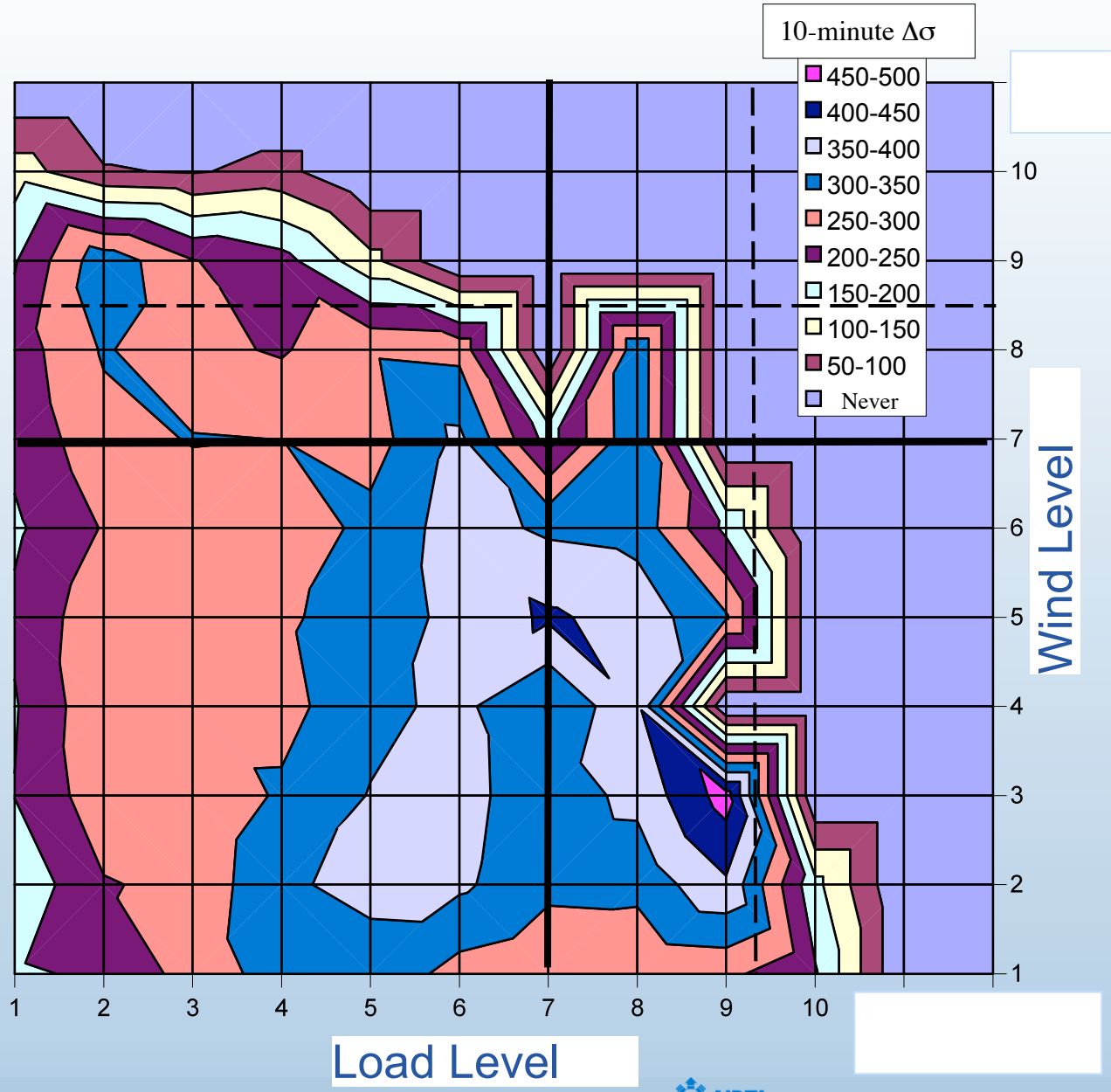
What is this plot ???

a. Each year has 8760 hours.
b. Load varies between a minimum and maximum
c. Wind power varies between zero and a maximum
d. The range of load and wind are each divided into 10 equal sized buckets
e. So, there are 100 combinations of load & wind
f. The value (color) at each intersection is the Net Load for that combination



Net Load Variability L30

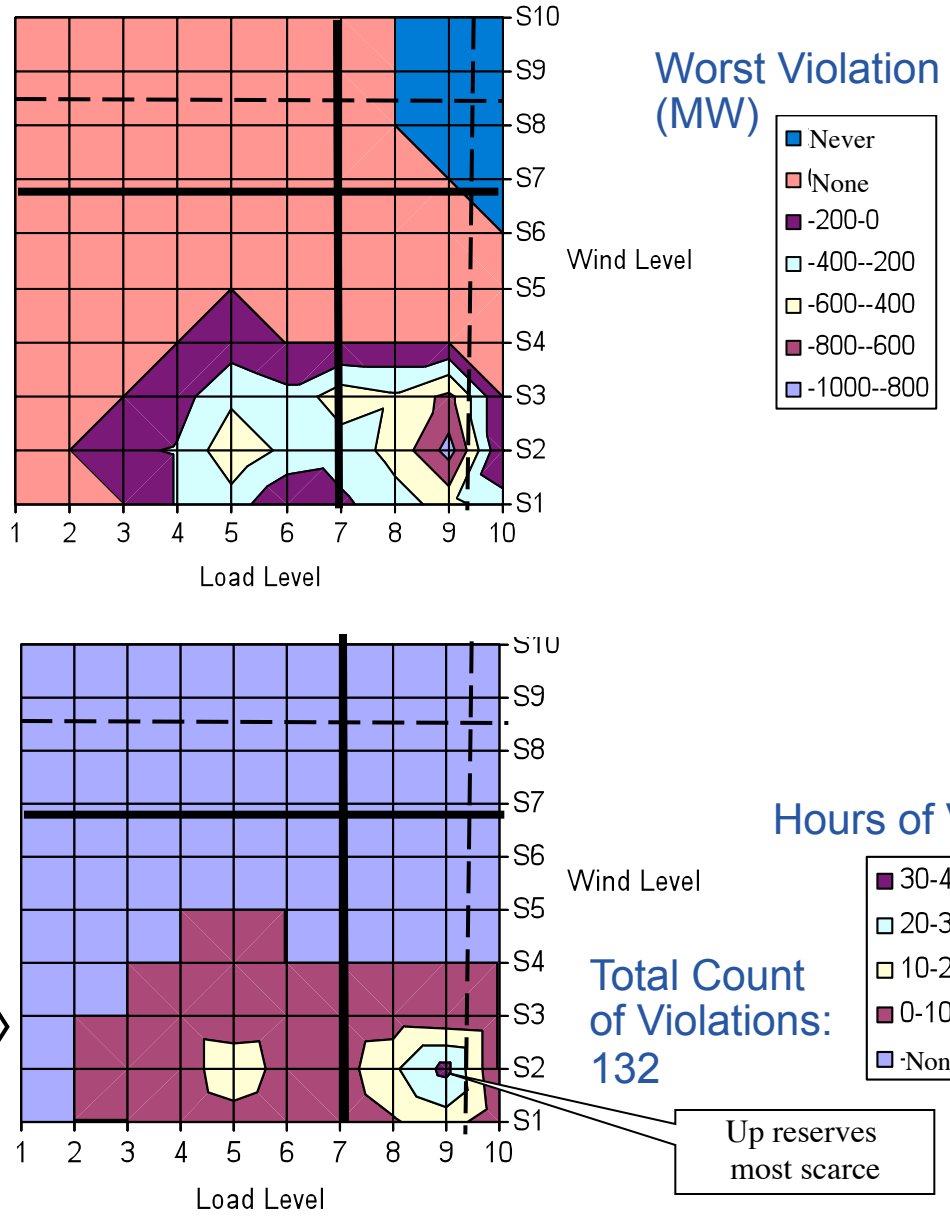
- Net load variability increases with wind
- Implied reserve requirement is 3 x $\Delta\sigma$
- Requirement is a function of both load level and wind level



L30R Case Up Reserve Violations

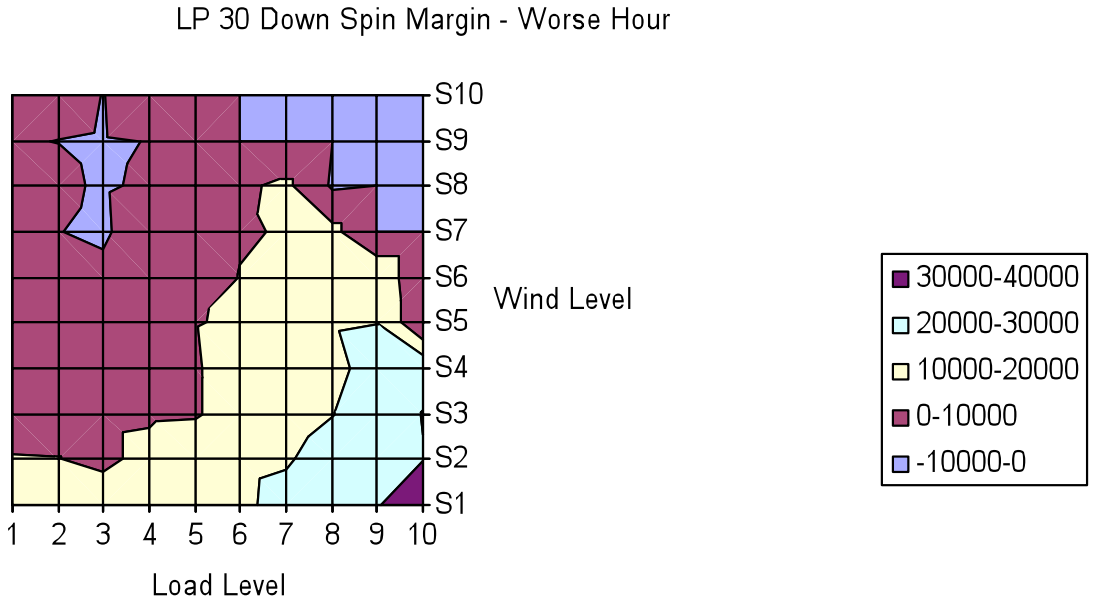
- Implied reserve requirement is 3 x σ 10-min Δ Net Load
- Violation if **Up Range** (from MAPS case) < 3σ
- Violation means hour has insufficient reserves to meet implied requirement. Load is still served.

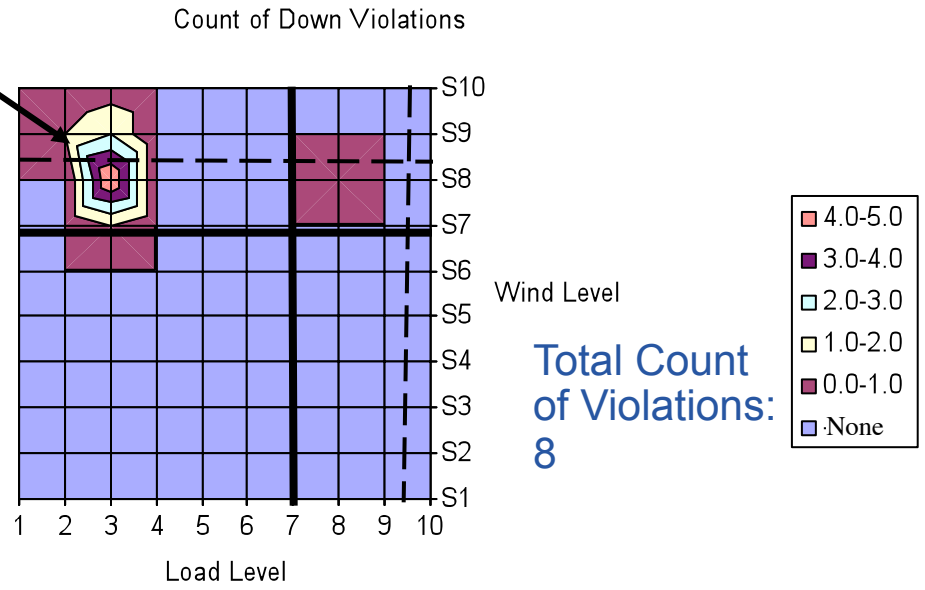
Scarcity of reserves at very high load aggravated by increased reserve requirement due to wind variability



L30R Case Down Reserve Violations

- Scarcity of down reserves at very high wind and relatively light load is consistent with other results





Total Count of Violations: 8

Intra-hour Variability - Summary

- Intra-hour variability increases with wind
- Smaller the ‘circle’, bigger the effect
- On FP or WECC level, variability ‘looks’ similar..change is incremental, not revolutionary
- On Area (state) level, variability starts to look very different… eventually dominated completely by wind (e.g. WY)
- On smaller (e.g. zonal) basis, variability clearly intractable…2 orders of magnitude increase…old rules unsuitable/ impossible
- Examination of subhourly performance suggests that rationally committed and dispatched systems, using imperfect DAH wind forecasts, can work well, if reserve resources are shared.
- Modified (usable, practical) rules for spin appear possible

For More Information

- Next steps
  - Finalize reserve analysis, quasi-steady-state analysis
  - New scenario - 20% wind/3% solar throughout WECC
  - Storage, PHEV, demand response analysis
  - Draft report end of 2009; stakeholder meeting
- WWSIS
  - Website at http://westconnect.com/planning_nrel.php
  - Solar dataset at: http://mercator.nrel.gov/wwsi/
- Upcoming PV Variability Meeting - Oct 7
  - Held in conjunction with UWIG (Oct 7-9, Cedar Rapids, Iowa, http://www.uwig.org/)
- Questions?
  - Debra Lew: Debra.Lew@nrel.gov
  - 303-384-7037

EXTRA SLIDES

Study Assumptions

- 2017 Fuel Prices:
  - Coal ~ $2.00/MBtu
  - Natural Gas ~$9.5/MBtu
- Carbon Tax : $30/ton
- Energy Velocity Database
  - ~24 GW capacity added 2009-2017 timeframe to maintain reserve margins (~11GW not in plans)
- NERC ES&D Peak Load Projections
- Economically Rational, WECC-wide Commitment and Dispatch recognizing transmission limitations.

Case Naming Convention

- Scenario – Penetration – Forecast – Sensitivity
- For Example : I 20 R t

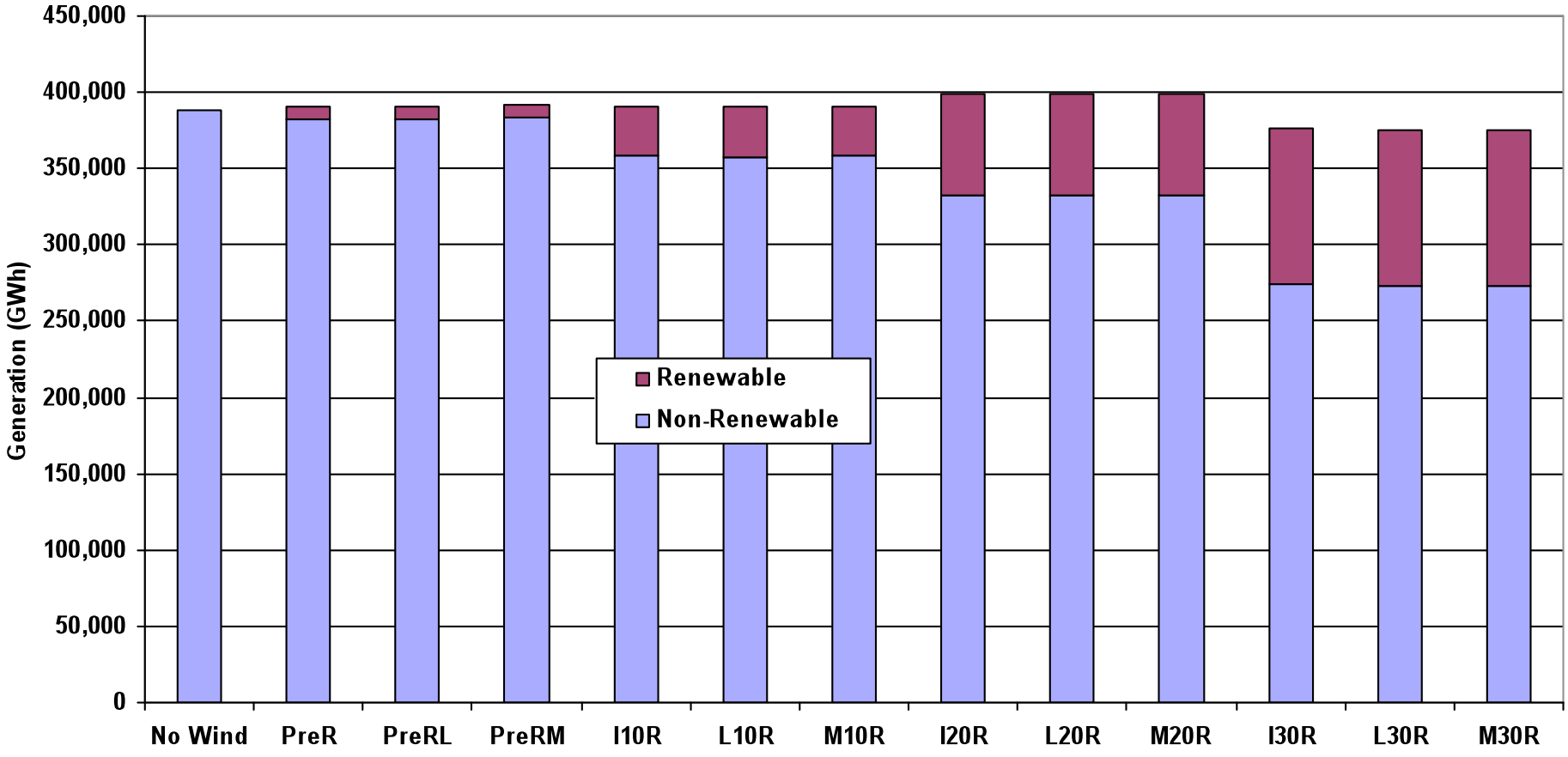
  In Area

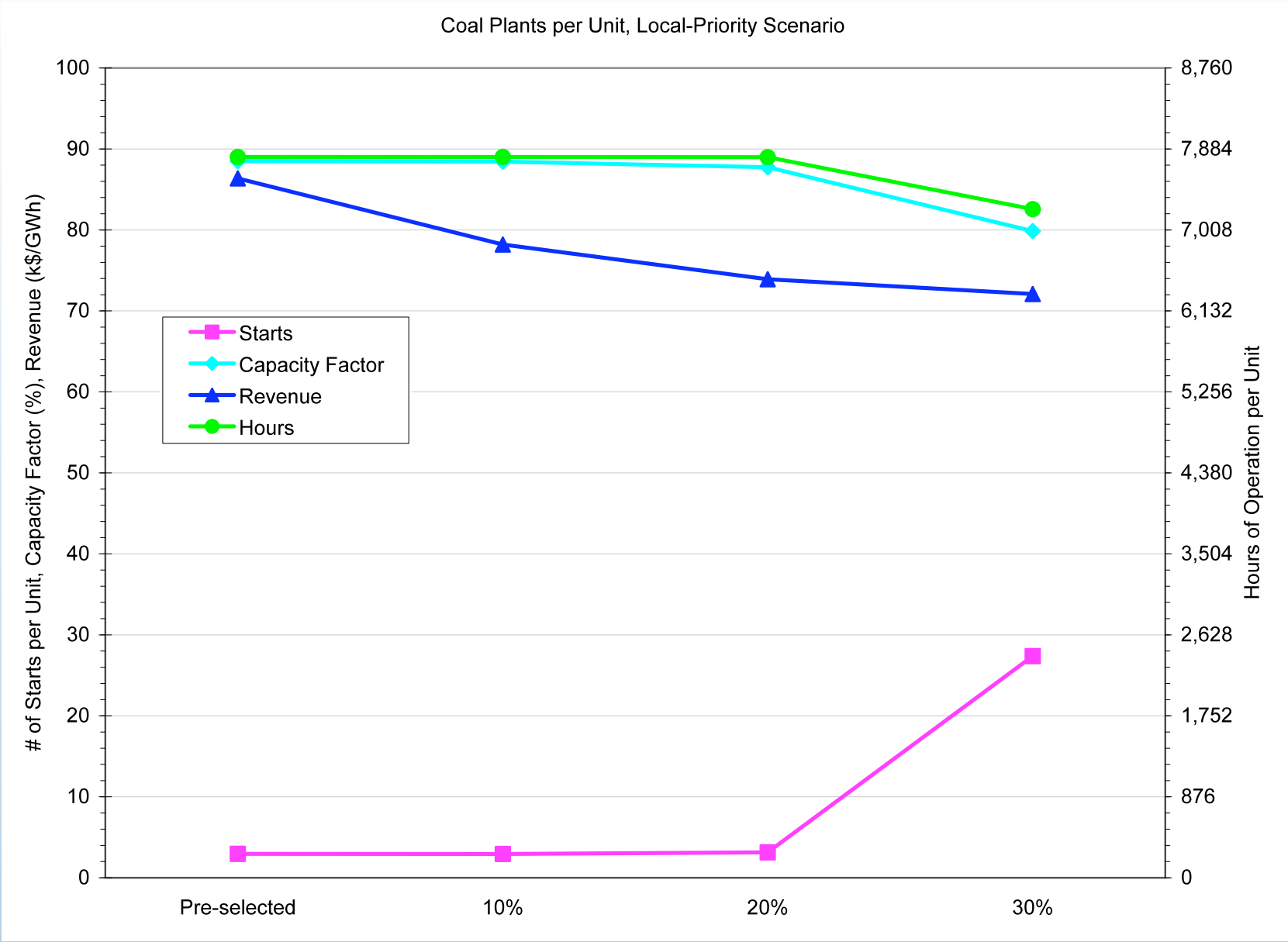
  20% penetration

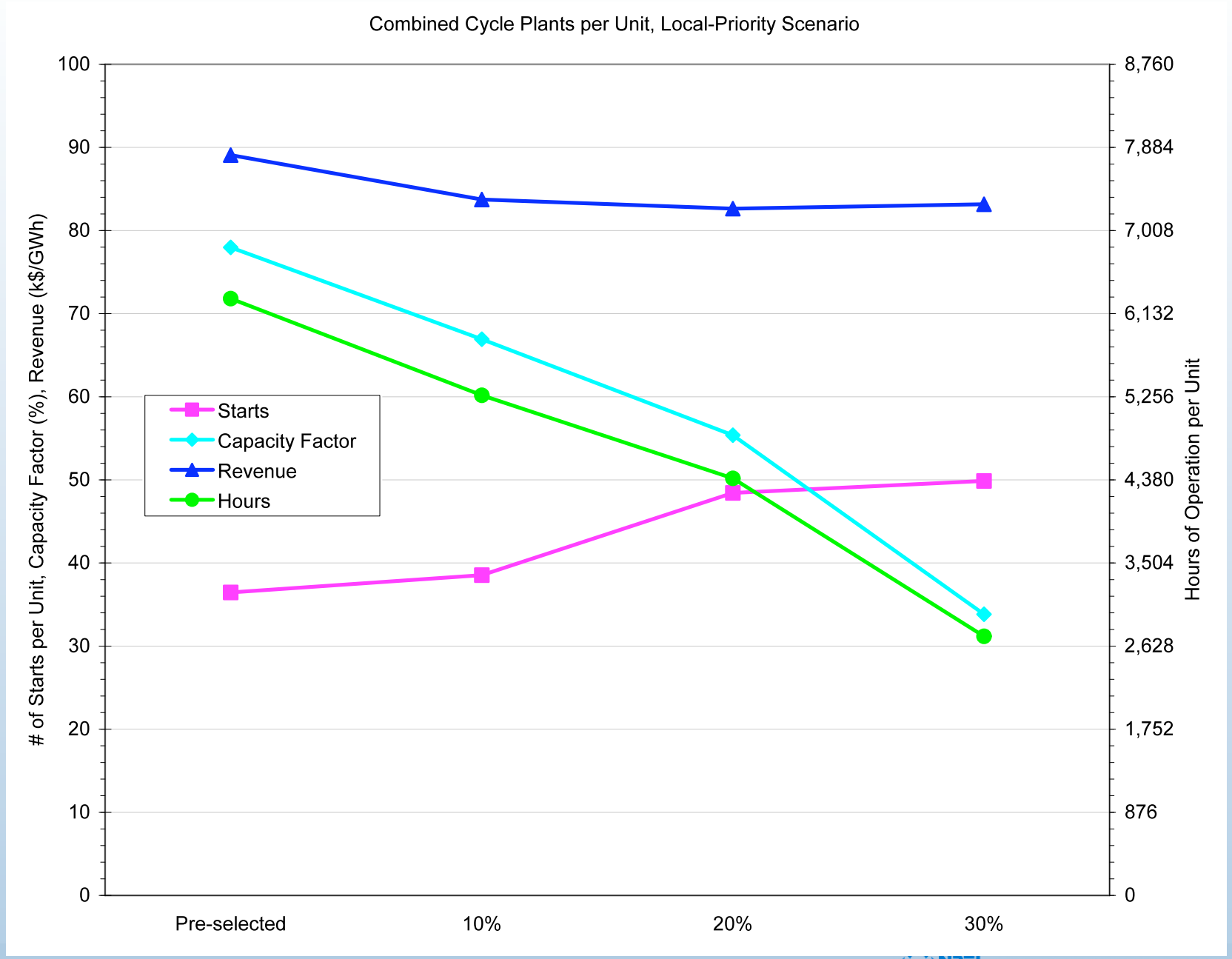
  Reduced (unbiased) Forecast

  transmission sensitivity

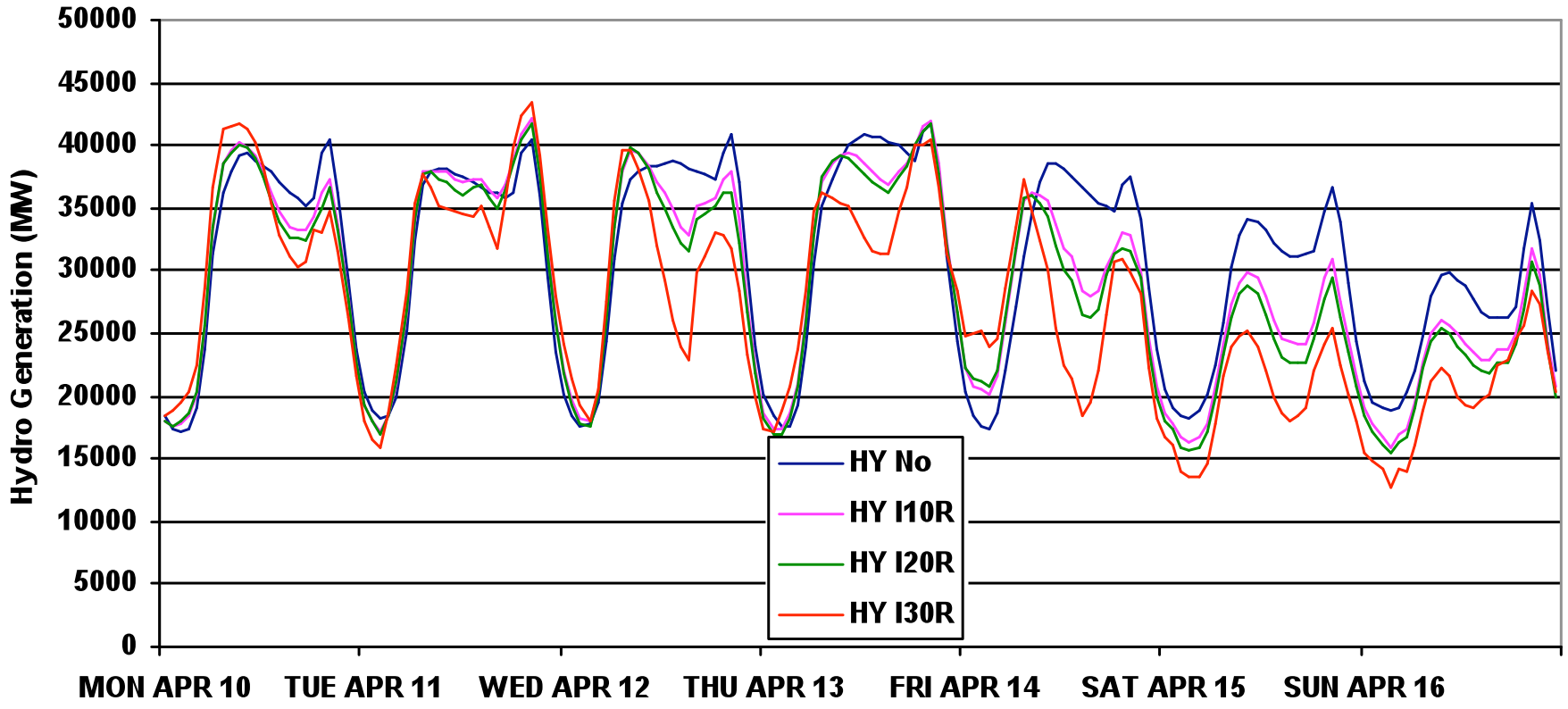
Total Generation - Study Area - 2006




Coal Plants per Unit, Local-Priority Scenario
# of Starts per Unit, Capacity Factor (%), Revenue (k$/GWh)
Hours of Operation per Unit
100
90
80
70
60
50
40
30
20
10
0
8,760
7,884
7,008
6,132
5,256
4,380
3,504
2,628
1,752
876
0
Starts
Capacity Factor
Revenue
Hours
Pre-selected
10%
20%
30%


Combined Cycle Plants per Unit, Local-Priority Scenario
# of Starts per Unit, Capacity Factor (%), Revenue (k$/GWh)
Hours of Operation per Unit
100
90
80
70
60
50
40
30
20
10
0
8,760
7,884
7,008
6,132
5,256
4,380
3,504
2,628
1,752
876
0
Starts
Capacity Factor
Revenue
Hours
Pre-selected
10%
20%
30%

Hydro Operation - Week of April 10th



Hydro Operation - Week of July 10th